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ABSTRACT

Forty-two enlisted men and women with no prior knowledge about electronics maintenance or logic diagrams participated in research designed to collect preliminary data on the training effectiveness of a problem solving computerized game for teaching electronics maintenance. Two games available on the University of Illinois PLATO Computer-Based Education System, a logic game and a game of chance, were modified for use in the experiment. Using a transfer of training paradigm three groups of subjects received one of the following treatments: instruction and practice in interpreting logic circuit diagrams, played a game of chance, or played a logic-based game. All subjects then received instruction and practice in interpreting logic circuit diagrams, or additional practice. Finally, all subjects were tested on their ability to interpret logic circuit diagrams. Results indicated that under certain conditions, limited practice in reading logic circuit diagrams when combined with playing a logic game is as effective as spending the same amount of time in practicing reading a more extensive set of diagrams. However, this is not the case when the limited practice is combined with playing a game of chance. (CMV)

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AN EMPIRICAL VALIDATION OF THE EFFECTIVENESS OF A COMPUTERIZED GAME TO TEACH TROUBLESHOOTING

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AN EMPIRICAL VALIDATION OF THE EFFECTIVENESS OF A COMPUTERIZED GAME TO TEACH TROUBLESHOOTING[1]

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The recent increases in the use of instructional games within the educational, industrial, and business communities can be attributed to the high interest and motivation they appear to generate among users (Shubick, 1975). Games also appear to provide a simulated environment within which information acquisition, information processing, and decision making skills can be developed and maintained. Yet, even though the use of gaming techniques for instruction and training has an intrinsic appeal, there is very little systematic evidence that instructional games actually teach what they are designed to teach. Further, aids to assist instructional game developers in designing training-effective games do not exist because there are insufficient behavioral data on the critical learner and task variables in game-based learning.

Research in game-based training has recently been initiated at the Army Research Institute (ARI). The first phase of the research is concerned with the training effectiveness of games for military duty related tasks.

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If this research is successful, subsequent research will be directed towards identifying relevant learner and task variables for effective game-based learning. The ultimate goal of this research is to develop guidelines for the design of training effective games.

The purpose of the research described here was to collect preliminary data on the training effectiveness of a problem solving game for a duty related task - electronics maintenance. Successful performance in the game depends upon eliminating logically incorrect alternatives. Alternative elimination also appears to be a required skill for successful electronics maintenance. Using a transfer of training paradigm three groups of soldiers either received instruction and practice in interpreting logic circuit diagrams, played a game of chance, or played a logic-based game; all soldiers then received instruction and practice in interpreting logic circuit diagrams, or additional practice; finally, all subjects were tested on their ability to interpret logic circuit diagrams.

METHOD

Subjects

Forty-two enlisted men and women stationed at Fort Belvoir, VA served as subjects. Subjects had no prior knowledge about either electronics maintenance or logic diagrams. Data from three subjects were eliminated because they failed to complete the experimental session. Subjects were randomly assigned to one of three groups, either the logic game group ($n = 13$), the control game group ($n = 12$), or the logic control group ($n = 14$).

Apparatus and Materials

Two games available on the University of Illinois PLATO Computer-Based Education System, a logic game and a game of chance, were modified for use in the experiment. Modifications included adding data collection routines and expanding instructions. Both games were played on PLATO IV terminals at Fort Belvoir, Virginia which were connected by dedicated telecommunications lines to the University of Illinois PLATO System in Urbana, Illinois. (See Smith and Sherwood, 1976, for a description of the system). To start a game session the subject was seated at the terminal and received on-line instruction on use of the keyboard. Following the equipment orientation, the subject received on-line game instruction, supplemented by instructions supplied by the experimenter. Supplemental instructions and help were available to all subjects throughout the game session.

Subjects playing the logic game were required to derive a hidden sequence of four digits which had been sampled without replacement from the digits 1-8 and randomly assigned to positions. The first game trial was necessarily a guess, and after each trial feedback on the accuracy of the guess was provided. Subjects were told (a) how many digits in their guess were correctly identified and placed in the correct sequence position, and (b) how many digits in their guess were correctly identified but had been placed in the wrong position. This information could be used to eliminate wrong alternatives on subsequent guesses. If, the subject had not discovered the correct solution within eight trials, the solution was shown to him and a new game begun. A different random sequence of digits was generated for each subject for each game. The control game was an on-line version of blackjack in which the subject played against the computer.

The initial stake was $1000. If they lost their stake, subjects were permitted to continue with an additional $1000 in PLATO money. The game rules were the traditional blackjack rules.

Because the focus of the transfer task was upon an understanding of logic functions rather than logic symbols, standard symbols were not used in diagram construction. To reduce the probability of identification errors, the symbols indicating the five logic functions used in this research, AND, NAND, OR, NOR, and INVERSION, were simple geometric shapes and were redundantly labelled with the names of the appropriate logic function.

Six levels of logic diagrams, levels A through F, were constructed. Levels varied in one or more of the following ways: the number of different logic functions, the total number of logic elements, and the number of inversions. A summary of the different logic diagram levels is shown in Table 1.

Procedure

Four to eight subjects were run in each experimental session. After a general orientation they were exposed to one of the three training conditions: logic game, control game, or logic control. Although training activities differed, the amount of time spent in training was equated for all conditions. Following training, all subjects were given a transfer test of their knowledge of interpreting logic circuit diagrams.

Training Sessions. The logic control group received paper and pencil instruction on the five logic functions and other features of the logic circuit diagrams. They were then given practice providing outputs (either 0's or 1's) as required on diagrams. Each diagram had the correct answer(s)

penciled on the back. Subjects were instructed to solve all problems on a given diagram before checking their answers. Help was provided by an experimenter upon request. Subjects in the logic control group moved serially from level A to level F diagrams and practiced on a total of 55 diagrams prior to the transfer task.

Table 1. Logic Functions, Number of Inversion, Number of Logic Elements, Number of Possible Outputs, and Number of Practice Diagrams for the Six Levels of Logic Circuit Diagrams.

LEVEL	FUNCTIONS	# INVERSIONS	# ELEMENTS	# POSSIBLE RESPONSES POSSIBLE	# PRACTICE DIAGRAMS
A	AND, OR	0-1	2-3	1	10
B	AND, OR	2	9	3	5
C	AND, OR and either NAND or NOR	3-4	9	3	20
D	AND, OR, NAND, NOR	3-4	9	3	10
E	AND, OR, NAND, NOR	5	12	3	5
F	AND, OR, NAND, NOR	6-8	16	4	5

Subjects in the game conditions played either the logic game or the control game at a PLATO IV terminal for one hour. They were then given the same instruction as the logic control group on the five logic functions and other features of the logic circuit diagrams. Limited

practice with logic diagrams followed. The game group practiced only on level A, B, and C diagrams, for a total of 35 diagrams. As in the logic control group, each diagram had the correct answer(s) penciled on the back, and help was available upon request. Subjects moved serially through the levels, from level A to level C.

Transfer Session. The transfer materials consisted of 40 logic circuit diagrams, ten new diagrams from each of level C, D, E, and F. All groups used the same set of transfer materials and progressed serially from level C through F. Subjects were required to provide only one output per diagram as indicated by a question mark on the appropriate line. No feedback was given on the correctness of their responses. They were allowed one hour to answer as many problems as they could.

RESULTS

Four subjects in the Logic Control Group, three subjects in the Game Control Group, and two subjects in the Logic Game Group failed to complete all diagrams in the test booklets. Because of an experimenter error, two E Level diagrams were omitted from test booklets for six Logic Game subjects. For these reasons, all data were analyzed as proportion scores.

There were no differences in the proportion of possible test problems attempted by the three groups during the one hour transfer session, $F(2,36)=.63$. The mean proportion attempted by the Logic Game, Logic Control, and Control Game groups was .955, .979, and .931, respectively.

Results of the transfer session were further analyzed using two measures, performance and accuracy. Performance is the proportion of possible test items correctly labelled by the subject, regardless of the

number of test items completed. In the performance score, failure to attempt an item within the one hour time limit is treated as an incorrect answer. The accuracy score is the proportion of logic diagrams attempted for which the subject provided the correct output. The accuracy score indicates the subject's understanding of logic functions without considering speed of responding.

Performance and accuracy were analyzed as a function of levels of logic circuit diagrams. Because of the confounding of levels and order of presentation, an alternative view is that performance and accuracy were analyzed as a function of blocks of trials. To simplify the presentation, the term "levels" will consistently be used as the reference variable.

Accuracy.

The mean accuracy scores on the transfer test, collapsed across levels for the Logic Game, Logic Control and Control Game Groups were .70, .86, and .60 respectively. All groups performed at greater than chance level, X^2 (2(1)=10.52, $p < .01$ or better, and a one-way analysis of variance (ANOVA) indicated a reliable effect of group membership on accuracy, $F(2,36)=7.29$ $p < .01$. The Logic Control Group was more accurate than either the Logic Game Group, $t(36)=2.489$ p .02, or the Control Game Group $t(36)=4.24$, $p < .01$. Although the mean accuracy score for the Logic Game Group was superior to the accuracy score for the Control Game Group, the difference was not reliable, $t(36)=1.39$.

The accuracy data were also analyzed using a two-way ANOVA, Groups x Levels, with repeated measures on the levels variable. For this

analysis, the data from the three subjects (two from the Game Control Group and one from the Logic Control Group) who failed to reach Level F diagrams were not included. Table 2 shows the mean accuracy score for each group at each diagram level. Because the Groups x Levels interaction was significant, $F(6,99)=2.44$, $p < .01$, simple main effects analyses were performed on both variables.

The accuracy scores of the Logic Control Group and the Control Game Group did not vary as a function of level, $F(3,99) < 1$, and $F(3,99)=2.31$, respectively. Accuracy scores for the Logic Game Group did, however, change with diagram levels, $F(3,99)=6.69$, $p < .01$. Newman-Keuls tests indicated more accurate scores for the Logic Game Group at Level E than at other levels, $p < .05$ in all cases, which did not differ from one another.

Table 2. Group accuracy on test diagrams as a function of levels

	LEVEL			
Group	C	D	E	F
Logic Game	.61	.71	.82	.67
Logic Control	.92	.90	.90	.80
Game Control	.65	.62	.66	.58

Reliable effects of groups were obtained at each of the four levels, $F(2,132)=3.50$, $p < .05$, or better. Newman-Keuls tests indicated that

the Logic Control Group had higher accuracy scores than the Control Game Group at each level of diagrams, $p < .05$. The Logic Control Group also had higher accuracy scores than the Logic Game Group at levels C and D, $p < .05$, but not at Levels E and F. The Logic Game Group differed from the Control Game Group at Level E.

Performance

The mean performance score for each group at each level is shown in Table 3. Because of heterogeneity of variance, an arcsin transformation was applied to the performance scores. The Groups x Levels ANOVA for the performance data indicated reliable effects of Groups, $F(2,36)=11.03$, $p < .01$, and Levels, $F(3,108)=6.09$, $p < .01$. The interaction term fell short of reliability, $F(6, 108)=2.10$, $p < .10$. Newman-Keuls tests at the .05 level indicated that the Logic Game and Logic Control Groups had higher performance scores than the Control Game Group and that performance declined significantly at Level F as compared to each of the other levels.

Because this was an exploratory experiment and because the Groups x Levels interaction approached significance ($F=2.18$ required for significance at the .05 level), simple main effects analyses were performed on both variables.

Performance varied as a function diagram level in the Logic Control Group, $F(3,108)=4.91$, $p < .01$, and for the Control Game Group ($F(3,108)=3.81$, $p < .05$, but not for the Logic Game Group, $F(3,108)=1.60$. Newman-Keuls tests at the .05 level indicated that the Logic Control Group performed poorer at Level F than at the other levels, which did not differ from one another. For the Control Game Group, performance at both Levels E and F was significantly poorer than at Level C.

Table 3. Group performance on test diagrams as a function of levels

	LEVEL			
GROUP	C	D	E	F Logic Game
Logic Game	.58	.70	.79	.65
Logic Control	.89	.88	.89	.74
Game Control	.63	.62	.58	.49

Reliable simple main effects were obtained for groups at each level, $F(2,144)=4.55$, $p < .05$ or better. Newman-Keuls tests at the .05 level indicated that the Logic Control Group had higher performance scores than the Control Game Groups at all levels, and higher performance scores than the Logic Game Group at levels C, D, and E, but not Level F. Performance scores were higher for the Logic Game Group than the Control Game Group at levels D, E, and F.

DISCUSSION

The results of this preliminary study indicate that under certain conditions, limited practice in reading logic circuit diagrams when combined with playing a logic game like the one used here, is as effective as the same amount of time spent in practicing reading a more extensive set of diagrams. This is not true when the limited practice is combined with playing a game of chance, so these results cannot be attributed to any general transfer effects of game playing *per se*. Because both game groups had the same practice set of diagrams, yet significantly different accuracy and performance scores at some diagram levels, it also cannot

be argued that limited practice was sufficient for successful performance on the transfer test.

The results do not extend across all levels of diagrams, however. The only consistent finding to emerge across levels was that the logic control group was superior in both performance and accuracy to the control game group. At the lower levels of diagrams (i.e., C and D) the game groups did not differ from one another in either performance or accuracy, and both were inferior to the logic control group. Differences between the game groups only emerged at higher diagram levels (i.e., E and F) and it was only at the higher levels that the logic game groups performance and accuracy approached that of the logic control group. The reasons for this effect are unclear. Both game groups had practiced on C level diagrams prior to the transfer test, but not on D, E, and F level diagrams as did the logic control group. The difference among levels of diagrams cannot be discretely articulated, but at least in some sense level F diagrams were more complex (contained more information) than level C diagrams. It could be that what was transferred from the training session for the logic game group to the transfer test was some minimal knowledge of the logic functions and operations (but not necessarily as good a knowledge as that of the logic control group) and some ability to decipher, transpose, reduce, and/or manipulate complex information and displays. This ability may not have been required at lower levels of diagrams.

The poorer performance and accuracy of the logic game group at lower diagram levels may also have been due to motivational factors. Proponents of instructional games emphasize motivational benefits of

games, but do not consider the possibility of a let-down when the player finds himself in the ordinary classroom or in a real-life situation in which he must apply what he has learned from the games. Observation of subjects in the logic control group indicated that they found the logic diagram problems quite interesting. On the other hand, some logic game subjects indicated some boredom, either verbally or by their behavior during instruction and practice with the logic diagrams as well as during the transfer test. If a motivational let-down was responsible for the logic game group's poor efficiency on the lower levels of diagrams, their subsequent improvement in the final levels suggests either that the group found those levels more challenging or that the motivational effect was a temporary one which dissipated rapidly. In any event, some attention should be paid to the possibility that the heightening of motivation during the game itself may be followed by a compensatory lowering of motivation for subsequent non-game activities. Such a possibility is consistent with the opponent process theory of motivation (Solomon and Corbit, 1974).

Caution must be observed in any explanation which is based solely on diagram complexity because of the confounding of time with levels. Indeed, the poor performance and accuracy for all groups on the final level of logic diagrams may be attributable to the one hour time limit to work on the logic diagrams. Because it was the final set, subjects may have proceeded more rapidly through level F diagrams than the earlier ones.

Additional research is underway to replicate and extend the results reported here.

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